SYSTEM AND METHOD FOR MONITORING OR REPORTING BATTERY STATUS OF IMPLANTABLE MEDICAL DEVICE

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This patent application is related to Stessman, U.S. Patent No. 6,584,355 entitled "SYSTEM AND METHOD FOR MEASURING BATTERY CURRENT," which is assigned to Cardiac Pacemakers, Inc., and which is incorporated by reference herein in its entirety, including its disclosure of tracking charge depletion from a battery.

This patent application is also related to Stessman et al. U.S. Patent Application No. 10/395,983, filed on March 25, 2003, entitled "SYSTEM AND METHOD FOR MEASURING BATTERY CURRENT," which is assigned to Cardiac Pacemakers, Inc., and which is incorporated by reference herein in its entirety.

This patent application is also related to James et al. U.S. Patent Application No. 10/618,095, filed on July 11 2003, entitled "INDICATOR OF REMAINING ENERGY IN STORAGE CELL OF IMPLANTABLE MEDICAL DEVICE," which is assigned to Cardiac Pacemakers, Inc., and which is incorporated by reference herein in its entirety.

This patent application is also related to Loch U.S. Patent Application No. 10/692,315, filed October 23, 2003, entitled "BATTERY CHARGE INDICATOR SUCH AS FOR AN IMPLANTABLE MEDICAL DEVICE," which is assigned to Cardiac Pacemakers, Inc., and which is incorporated by reference herein in its entirety.

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TECHNICAL FIELD

This patent application pertains generally to batteries, and more particularly, but not by way of limitation, to a system and method for monitoring or reporting battery status of an implantable medical device.

BACKGROUND

Implantable medical devices include, among other things, cardiac rhythm management (CRM) devices such as pacers, cardioverters, defibrillators, cardiac resynchronization therapy (CRT) devices, as well as combination devices that provide more than one of these therapy modalities to a subject. Such implantable devices are typically powered by a battery. When the battery's useful life has expired, the implanted device is typically explanted and replaced. Therefore, it is often useful to know how much battery energy has been used and/or how much battery energy remains.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, which are not necessarily drawn to scale, like numerals describe substantially similar components throughout the several views. Like numerals having different letter suffixes represent different instances of substantially similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

FIG. **1** is a schematic/block diagram illustrating generally one example of a system **100** that includes an implantable medical device and an external user interface device.

FIG. **2** is a flow chart illustrating generally one example of a technique of providing battery status information.

FIG. **3** is a flow chart illustrating generally a fault current detection process.

FIG. **4** is a flow chart illustrating generally an example of a further method including acts in addition to those illustrated in FIG. **2**.

FIG. **5** is a user interface display screenshot of a battery status screen **500** displayed on the display **124** of the user interface **104**.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. These embodiments, which are also referred to herein as "examples," are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that the embodiments may be combined, or that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims and their equivalents.

In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one. In this document, the term "or" is used to refer to a nonexclusive or, unless otherwise indicated. Furthermore, all publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though individually incorporated by reference. In the event of inconsistent usages between this documents and those documents so incorporated by reference, the usage in the incorporated reference(s) should be considered supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

FIG. **1** is a schematic/block diagram illustrating generally one example of a system **100**. In this example, the system **100** includes an implantable medical device **102**, such as a cardiac rhythm management device, for example. In this example, the system **100** also includes an external programmer or other user interface device **104**. The user interface **104** is operatively communicatively

coupled to the device **102**, such as by using a wireless or other communications link **106**.

In the example of FIG. **1**, the device **102** includes a battery **108**. The battery **108** provides electrical energy to load circuits **110** of the device **102**. It is useful to know how much of the stored energy of the battery **108** has been used (or, alternatively, how much usable energy remains in the battery **108**). Among other things, such battery status information helps a physician or other user plan for when the implantable medical device **102** should be explanted from a subject and replaced by another device having a fresh battery.

One technique for determining the battery status measures the battery terminal voltage. The measured battery terminal voltage is used directly to provide a battery status indicator. However, such a technique may be ineffective for certain battery chemistries (e.g., a Lithium Carbon Monofluoride "LiCFx" battery) that manifest a relatively flat battery terminal voltage from the beginning and over most of the battery's useful life. Another technique for determining battery status, such as for an implantable defibrillator, measures an elapsed time for charging a defibrillation capacitor to infer the battery status. Such an elapsed time increases along with the internal battery impedance, which increases as the battery is depleted of charge. However, such a technique is also ineffective for certain battery chemistries (e.g., a LiCFx battery, which has a very low internal battery resistance that does not change appreciably during a time from the beginning and over most of the battery's useful life). By contrast, the system **100** of FIG. **1** provides an alternative way to provide battery status information throughout the battery's useful life, even for a LiCFx battery, or for other batteries having similar battery terminal voltage and/or battery impedance characteristics.

In the example of FIG. **1**, the device **102** includes a battery terminal voltage measurement circuit **112**, a battery charge measurement circuit **114**, a controller circuit **116**, a communication circuit **118**, and a temperature sensor circuit **120**. In this example, the battery terminal voltage measurement circuit **112** is connected in parallel with the battery **108**, i.e., across the battery terminals of the battery **108**.

The battery charge measurement circuit **114** is connected in series with the battery **108**, i.e., between the battery **108** and the load circuits **110**. The controller **116** is coupled to the battery terminal voltage measurement circuit **112**, the battery charge measurement circuit **114**, and the temperature sensor circuit **120** to respectively receive a battery terminal voltage measurement, a battery current measurement, and a device **102** temperature measurement. In one example, the battery charge measurement circuit **114** is a battery charge and current measurement circuit, such as described in the above-incorporated Stessman U.S. Patent No. 6,584,355. In the example of FIG. **1**, the external user interface **104** includes a communication circuit **122** and a display **124**.

FIG. **2** is a flow chart illustrating generally one example of a technique of providing battery status information, such as by using the system **100** of FIG. **1**. At **200**, a battery terminal voltage is measured, such as by using the battery terminal voltage measurement circuit **112**. At **202**, a charge delivered by the battery **108** is measured, such as by using the battery charge and battery current measurement circuit described in the above-incorporated Stessman U.S. Patent No. 6,584,355. At **204**, a first voltage threshold is established using a rate of charge delivered by the battery. Therefore, the first voltage threshold is a function of the battery current. The exact function may vary, such as to obtain a desired degree of accuracy in the appropriate first voltage threshold over a range of battery current drains. In one illustrative example of the particular function (but not by way of limitation) for a particular battery chemistry and design, if the measured battery current exceeds a particular current threshold value (e.g., 45 microamperes), then a first voltage threshold value of 2.81 Volts is established, otherwise a different first voltage threshold value of 2.78 Volts is established (additional current threshold values and corresponding first voltage thresholds could also be used). In one example, an average of the measured battery current (e.g., over an averaging time period of about 1 week) is used for comparing against the current threshold. In one example, this comparison of average measured battery current to the current threshold is performed once each such averaging time period.

At **206**, a measured battery terminal voltage is compared to the first voltage threshold that was established at **204**. At **208**, if the measured battery terminal voltage exceeds the first voltage threshold, then at **210** a battery charge status indicator is computed using the measurement of how much charge has been previously delivered by the battery **108**. At **212**, this charge-delivered based battery status indicator is then communicated to the user, such as over communication link **106** for display to the user on the display **124** of the user interface **104**. In one example, this communication takes place the next time that the device **102** is interrogated by the user interface **104**, however, this communication could alternatively be initiated by the device **102** rather than the user interface **104**.

At **208**, if the measured battery terminal voltage does not exceed the first voltage threshold, then an elective replacement indicator ("ERI") flag is set at **214**. Assertion of the ERI flag corresponds to a predicted subsequent time period (e.g., 6 months) before battery expiration is expected. In this example, assertion of the ERI flag also triggers a switch from a charge-delivered based battery status indicator to subsequent use of a battery terminal voltage based battery status indicator. After ERI is asserted, the battery terminal voltage based battery status indicator (e.g., "ERI asserted") is communicated at **212** to the user. In one example, this communication takes place the next time that the device **102** is interrogated by the user interface **104**, however, this communication could alternatively be initiated by the device **102** rather than the user interface **104**.

In the method discussed above with respect to FIG. **2**, operation has been described, for conceptual clarity, using a single comparison of the battery voltage to the first voltage threshold to determine whether to assert ERI. However, in a further example, ERI is only asserted if three consecutive such comparisons indicate a battery voltage that has fallen below the first voltage threshold. Each such comparison of the battery voltage to the first voltage is made about once per day (e.g., every 21 hours). In one example, the battery voltage reading is an average reading over the same time period of about once per day (e.g., 21 hours).

Moreover, in the method illustrated in FIG. **2**, storage of the battery at a cold temperature (e.g., if the implantable device **102** is left in an automobile trunk in a cold climate) may cause the battery terminal voltage to droop. However, such temporary temperature-related drops in battery terminal voltage are not indicative of the state of the battery's charge. The battery terminal voltage will recover when the device **102** is implanted into a patient and the device **102** is warmed to the patient's body temperature. Accordingly, in one example, the device **102** includes a temperature sensor **120** to measure the temperature of the device. The temperature is compared to a temperature threshold (e.g., about 10 degrees Celsius, or some other suitable temperature threshold). If the device **102** temperature falls below the temperature threshold, then the battery voltage measurement is discounted (e.g., inhibited or ignored), at least for the purposes of making a comparison to a voltage threshold for asserting ERI.

FIG. **3** is a flow chart illustrating generally a fault current detection process. In one example, the fault current detection process runs concurrent with **202** or one of the other acts illustrated in FIG. **2**. At **300**, a shipping state of the device **102** is determined, such as by reading a memory storage location that includes such information. The shipping state of the device **102** indicates whether the device is in a shipping mode, which is the state of the device **102** when it leaves the manufacturing facility. After the device **102** has been implanted in a patient, it is programmed out of the shipping mode by the user. At **302**, a fault current detection threshold is set, such as by using the shipping state information. In one illustrative example, if the shipping state indicates that the device **102** is in a shipping mode, then the fault current detection threshold is set to 24 microamperes (or other suitable value for detecting an abnormally elevated current in the shipping mode). In this example, if the shipping state indicates that the device **102** has been implanted in a patient, then the fault current detection threshold is set to 200 microamperes (or other suitable value for detecting an abnormally elevated current in the implanted mode).

At **304**, a battery current is monitored, such as by using the battery charge measurement circuit **114**, as discussed above. At **306**, the monitored battery current is averaged, such as by the controller **116**, over a suitable averaging time period (for example, about 1 day, such as about 21 hours) for performing the fault current detection. This averaging time period may be different than the averaging time period discussed above for establishing the first voltage threshold using the monitored battery current. At **308**, the average current is compared (e.g., once per averaging period) to the fault current detection threshold that was set at **302**. At **310**, if the average current exceeds the fault current detection threshold, then a fault current detection condition is declared at **312**, and the assertion of the fault current detection condition is communicated to the user at **314**. Otherwise, if at **310** the average current does not exceed the fault current detection threshold, then process flow returns to **300**.

In one example, the average current must exceed the fault current detection threshold for two consecutive averaging time periods for the fault condition to be declared at **312**.

FIG. **4** is a flow chart illustrating generally an example of a further method including acts in addition to those illustrated in FIG. **2**. In the example of FIG. **4**, at **400**, process flow continues from **212** of FIG. **2**. At **402**, if ERI has not yet been asserted, then at **404** process flow continues to **200** of FIG. **2**. At **402**, if ERI has been asserted, then at **406** a battery terminal voltage is measured, such as by using the battery terminal voltage measurement circuit **112**. At **408**, a charge delivered by the battery **108** is measured, such as by using the battery charge and battery current measurement circuit described in the above-incorporated Stessman U.S. Patent No. 6,584,355. At **410**, a second voltage threshold is established using a rate of charge delivered by the battery. The second voltage threshold is a function of the battery current; the exact function may vary, such as to obtain a desired degree of accuracy in the appropriate threshold voltage over a range of battery current drains. In one illustrative example, if the battery current exceeds a particular current threshold value (e.g., 45 microamperes), then a second voltage threshold value of 2.52 Volts is

used, otherwise a different second voltage threshold value of 2.50 Volts is used. In one example, an average of the measured battery current (e.g., over an averaging time period of about 1 week) is used for comparing against the current threshold. In one example, this comparison is performed once each such averaging time period.

At **412**, a measured battery terminal voltage is compared to the second voltage threshold that was established at **410**. At **414**, if the measured battery terminal voltage exceeds the second voltage threshold, then process flow returns to **406**, otherwise process flow continues to **416**, where an end of life ("EOL") flag is set at **416**. Assertion of the EOL flag corresponds to a predicted subsequent time period (e.g., 3 months) before battery expiration is expected. In this example, assertion of the EOL flag also optionally alters device **102** functionality at **418**. In one such example, assertion of the EOL flag results in turning off one or more of: diagnostic features, rate responsive pacing, atrial pacing, and/or bi-ventricular pacing. After EOL is asserted, the battery terminal voltage based battery status indicator (e.g., "EOL asserted") is communicated at **420** to the user. In one example, this communication takes place the next time that the device **102** is interrogated by the user interface **104**, however, this communication could alternatively be initiated by the device **102** rather than the user interface **104**. In one example, the battery voltage measurement is discounted (at least for the purposes of making a comparison to a voltage threshold for asserting ERI) if the temperature of the device **102** falls below a threshold value, as discussed above with respect to FIG. **2**.

In the method discussed above with respect to FIG. **4**, operation has been described, for conceptual clarity, using a single comparison of the battery voltage to the second voltage threshold to determine whether to assert EOL. However, in a further example, EOL is only asserted if three consecutive such comparisons indicate a battery voltage that has fallen below the second voltage threshold. Each such comparison of the battery voltage to the second voltage is made about once per day (e.g., every 21 hours). In one example, the battery voltage reading is an average reading over the same time period of about once per day (e.g., 21 hours). Moreover,

if the device **102** is in a pre-ERI state, and receives three consecutive battery voltage comparisons below the second voltage threshold, then both ERI and EOL are asserted; the device **102** need not spend time in the intermediate ERI state.

FIG. **5** is a user interface display screenshot of a battery status screen **500** displayed on the display **124** of the user interface **104**. In this example, the battery status screen **500** includes a "gas gauge" type of meter **502** displaying a needle **504** that moves from a beginning of life ("BOL") position to an ERI position, and then to an EOL position as charge is depleted from the battery **108**. During the time between BOL and ERI, the "gas gauge" type of meter indication of battery charge status is derived from measuring charge depleted from the battery, as discussed above. Upon detection of ERI and thereafter, the "gas gauge" type of meter indication of battery charge status is derived from the measured battery terminal voltage, as discussed above. In this example, the battery status screen also includes information about one or more of: the date of the last battery test, a qualitative indicator of battery status (e.g., "good," "bad," etc.), a magnet rate (i.e., a fixed rate that will result from placing a magnet near the device **102**, where the value of the fixed rate will be different depending on the battery status, e.g., 100 ppm between BOL and ERI, 85 ppm between ERI and EOL, and less than or equal to 85 ppm after EOL), a time since the device **102** was implanted, and/or a longevity remaining at the programmed pacing parameters (e.g., pulsewidth, amplitude, and pacing mode).

It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments may be used in combination with each other. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Moreover, in the

following claims, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.